

## TABLE OF CONTENTS

	<u>Page</u>
<b>EXECUTIVE SUMMARY</b>	<b>ES-1</b>
Wastewater Challenges in South Florida	ES-1
Congressional Mandate for Relative Risk Assessment	ES-2
Municipal Wastewater Treatment Options in South Florida	ES-2
Wastewater Treatment Options	ES-3
Levels of Wastewater Treatment and Disinfection	ES-4
Risk Assessment	ES-5
Approach Used in this Relative Risk Assessment	ES-6
Deep-Well Injection	ES-7
Regulatory Oversight of Deep-Well Injection	ES-10
Option-Specific Risk Analysis for Deep-Well Injection	ES-11
How Injected Wastewater Can Reach Drinking-Water Supplies	ES-11
Human Health and Ecological Risk Characterization of Deep-Well Injection	ES-13
Aquifer Recharge	ES-14
Regulatory Oversight of Aquifer Recharge	ES-14
Option-Specific Risk Analysis for Aquifer Recharge	ES-15
Human Health and Ecological Risk Characterization of Aquifer Recharge	ES-16
Discharge to Ocean Outfalls	ES-16
Regulatory Oversight of Discharge to Ocean Outfalls	ES-17
Option-Specific Risk Analysis for Discharge to Ocean Outfalls	ES-18
Human Health and Ecological Risk Characterization of Discharge to Ocean Outfalls	ES-19
Discharge to Surface Waters	ES-19
Regulatory Oversight of Discharge to Surface Waters	ES-20
Option-Specific Risk Analysis for Discharge to Surface Waters	ES-20
Human Health and Ecological Risk Characterization of Discharge to Surface Waters	ES-22
Overall Risk Assessment	ES-23
Findings on Risk to Human Health	ES-24
Findings on Risk to Ecological Health	ES-24
References	ES-26
 <b>1.0 INTRODUCTION</b>	 <b>1-1</b>
1.1 Congressional Mandate	1-1
1.2 Purpose	1-1

<b>2.0</b>	<b>BACKGROUND</b>	<b>2-1</b>
2.1	Wastewater Management Options Used in South Florida	2-1
2.1.1	Class I Deep Well Injection	2-5
2.1.2	Aquifer Recharge	2-6
2.1.3	Ocean Outfalls	2-6
2.1.4	Surface Water Discharges	2-7
2.2	Drinking Water in South Florida	2-7
2.2.1	Floridan Aquifer System	2-9
2.2.2	Biscayne Aquifer System	2-10
2.2.3	Surficial Aquifer	2-10
2.2.4	Drinking Water Quality in South Florida Communities	2-10
2.3	General Description of Wastewater Treatment	2-11
2.3.1	Wastewater Treatment Methods Used in Florida	2-11
2.3.2	Definitions of Wastewater Treatment Methods and Levels of Disinfection	2-14
	References	2-16
<b>3.0</b>	<b>METHODOLOGY FOR RELATIVE RISK ASSESSMENT</b>	<b>3-1</b>
3.1	Generic Risk Analysis Framework and Problem Formulation	3-1
3.2	Option-Specific Risk Analysis and Risk Characterization	3-2
3.3	Relative Risk Assessment	3-3
3.4	Detailed Description of Problem Formulation	3-3
3.4.1	Selection of Potential Exposure Pathways	3-4
3.4.2	Definition of Potential Receptors	3-5
3.4.3	Selection of Assessment Endpoints	3-5
3.4.4	Selection of Potential Stressors	3-6
3.4.4.1	Pathogenic Microorganisms	3-8
3.4.4.2	Inorganic Stressors	3-12
3.4.4.3	Organic Compounds	3-15
3.5	Analysis Plan	3-19
3.6	Final Conceptual Model of Probable Risk	3-20
3.7	Relative Risk Assessment	3-21
	References	3-22
<b>4.0</b>	<b>DEEP WELL INJECTION</b>	<b>4-1</b>
4.1	Definition of the Deep-Well Injection Option	4-1
4.2	Deep-Well Capacity and Use in South Florida	4-1
4.3	Environment Into Which Treated Wastewater Is Discharged	4-1
4.3.1	Aquifers in South Florida	4-3
4.3.2	Regional Conditions in Dade County	4-8
4.3.3	Regional Conditions in Pinellas County	4-9
4.3.4	Regional Conditions in Brevard County	4-10
4.4	Ground Water Quality and Fluid Movement in South Florida	4-11

4.4.1	Dade County Groundwater Monitoring Information	4-14
4.4.2	Pinellas County Groundwater Monitoring Information	4-16
4.4.3	Brevard County Groundwater Monitoring Information	4-17
4.4.3.1	South Beaches	4-17
4.4.3.2	Palm Bay	4-18
4.5	Regulations and Requirements for the Deep-Well Injection Option	4-19
4.6	Problem Formulation	4-20
4.7	Conceptual Model of Potential Risks for the Deep-Well Injection Option	4-22
4.7.1	Potential Stressors	4-24
4.7.2	Potential Exposure Pathways	4-27
4.7.3	Potential Receptors and Assessment Endpoints	4-27
4.8	Risk Analysis of the Deep-Well Injection Option	4-28
4.8.1	Application of the Analytical Transport Model	4-29
4.8.2	Vertical Times of Travel and Horizontal Migration	4-35
4.8.2.1	Governing Assumptions for the Transport Model	4-36
4.8.2.2	Vertical Time-of-Travel Results and Discussion	4-36
4.8.2.3	Horizontal Migration	4-39
4.8.2.4	Transport Model Limitations	4-40
4.8.2.5	Uncertainty Analysis	4-41
4.8.3	Evaluation of Receptors and Analysis Endpoints	4-42
4.8.3.1	Application of the Stressor Fate and Transport Model	4-43
4.8.3.2	Final Concentrations of Chemical Stressors	4-45
4.8.3.3	Fate and Transport of Pathogenic Microorganisms	4-47
4.9	Final Conceptual Model of Risk for Deep-Well Injection	4-56
4.9.1	Injection Pressure Head and Buoyancy Pressure	4-58
4.9.2	Vertical Time-of-Travel	4-59
4.9.3	Horizontal Distance Traveled in a Given Travel Time	4-59
4.9.4	Fate of Chemical Constituents	4-60
4.9.5	Comparison with Monitoring-Well Data	4-60
4.9.6	Mechanical Integrity as a Risk Factor	4-60
4.9.7	Fate and Transport of Pathogenic Microorganisms	4-62
4.9.8	Effects of Data Gaps	4-63
	References	4-64
<b>5.0</b>	<b>AQUIFER RECHARGE</b>	<b>5-1</b>
5.1	Definition of Aquifer Recharge	5-1
5.2	Use of Aquifer Recharge in South Florida	5-2
5.3	Environment into which Treated Wastewater Is Discharged	5-5
5.3.1	Biscayne Aquifer System	5-5
5.3.2	Surficial Aquifer	5-5

5.4	Regulations and Requirements for Aquifer Recharge	5-6
5.4.1	Slow-Rate Land Application Systems	5-6
5.4.2	Rapid-Rate Land Application Systems	5-7
5.4.3	Wetland Systems	5-8
5.5	Problem Formulation	5-9
5.5.1	Slow-Rate Land Application Systems	5-9
5.5.2	Rapid-Rate Land Application Systems	5-10
5.5.3	Wetland Systems	5-11
5.5.4	Florida DEP Study of Relative Risks of Reuse	5-11
5.5.5	Potential Stressors	5-12
5.5.6	Potential Receptors and Assessment Endpoints	5-13
5.5.7	Potential Exposure Pathways	5-13
5.5.8	Conceptual Model of Potential Risks of Aquifer Recharge	5-14
5.6	Risk Analysis of the Aquifer Recharge Option	5-16
5.6.1	Vertical and Horizontal Times of Travel	5-16
5.6.2	Evaluation of Stressors	5-17
5.6.3	Evaluation of Receptors and Analysis Endpoints	5-19
5.7	Final Conceptual Model of Probable Risk	5-24
5.8	Potential Effects of Data Gaps	5-26
	References	5-28
<b>6.0</b>	<b>OCEAN OUTFALLS</b>	<b>6-1</b>
6.1	Definition of Ocean Outfalls	6-1
6.2	Capacity and Use in South Florida	6-1
6.3	Environment into Which Treated Wastewater is Discharged	6-5
6.4	Regulations and Requirements Concerning Ocean Outfalls	6-6
6.4.1	General Requirements	6-6
6.4.2	Secondary Treatment of Wastewater	6-8
6.4.3	Basic Disinfection	6-8
6.4.4	Water Quality Standards for Receiving Waters	6-9
6.5	Problem Formulation	6-10
6.5.1	Potential Stressors	6-10
6.5.1.1	Nutrients and Eutrophication	6-11
6.5.1.2	Pathogenic Microorganisms	6-13
6.5.1.3	Priority Pollutant Metals	6-15
6.5.1.4	Organic Compounds	6-15
6.5.2	Potential Receptors	6-16
6.5.2.1	Ecological Receptors	6-16
6.5.2.2	Human receptors	6-17
6.5.3	Potential Exposure Pathways	6-17
6.5.4	Conceptual Model of Potential Risk for Ocean Outfalls	6-18
6.6	Risk Analysis of Ocean Outfalls	6-21
6.6.1	Evaluation of Physical Transport	6-21
6.6.1.1	Transport, Dispersion and Dilution by Currents	6-22

6.6.1.2	Dilution of the Effluent Plume	6-23
6.6.2	Evaluation of Stressors, Exposure Pathways and Receptors	6-28
6.6.2.1	Pathogenic Microorganisms	6-28
6.6.2.2	Nutrients	6-32
6.6.2.3	Metals and Organic Compounds	6-37
6.6.2.4	Toxicity Testing of Effluent	6-40
6.6.3	Final Conceptual Model of Probable Risk for Ocean Outfalls	6-41
6.7	Potential Effects of Data Gaps	6-45
	References	6-46
<b>7.0</b>	<b>DISCHARGE TO SURFACE WATERS</b>	7-1
7.1	Definition of Discharge to Surface Waters	7-1
7.2	Use of Discharge-to-Surface-Waters Option in South Florida	7-1
7.3	Environment Into Which Treated Wastewater is Discharged	7-2
7.3.1	Estuarine Environments	7-2
7.3.1.1	Tampa Bay	7-3
7.3.1.2	Sarasota Bay	7-3
7.3.1.3	Indian River Lagoon	7-4
7.3.1.4	Florida Bay	7-4
7.3.2	Fresh Water Environments	7-5
7.4	Option-Specific Regulations and Requirements	7-7
7.4.1	Treatment and Disinfection Requirements	7-7
7.4.2	Standards for Surface-Water Quality	7-8
7.5	Problem Formulation	7-10
7.5.1	Potential Stressors	7-10
7.5.1.1	Nutrient Stressors	7-11
7.5.1.2	Metals	7-12
7.5.1.3	Organic Compounds	7-12
7.5.1.4	Pathogenic Microorganisms	7-13
7.5.1.5	Secondary Stressors	7-13
7.5.2	Potential Receptors and Assessment Endpoints	7-15
7.5.3	Potential Exposure Pathways	7-15
7.5.4	Conceptual Model of Potential Risk for the Discharge-to-Surface-Waters Option	7-16
7.6	Risk Analysis of the Discharge-to-Surface-Waters Option	7-17
7.6.1	Evaluation of Stressors and Assessment Endpoints	7-19
7.6.1.1	Nutrients	7-19
7.6.1.2	Metals	7-20
7.6.1.3	Organic Compounds	7-20
7.6.1.4	Pathogenic Microorganisms	7-21
7.6.2	Evaluation of Receptors and Exposure Pathways	7-21
7.7	Final Conceptual Model of Discharge-to-Surface-Waters Option	7-24
7.8	Gaps in Knowledge	7-26
	References	7-27

<b>8.0</b>	<b>RELATIVE RISK ASSESSMENT</b>	<b>8-1</b>
8.1	Identified Risk Issues	8-1
8.1.1	Wastewater Treatment and Disinfection	8-8
8.1.2	Large-scale Transport Processes	8-9
8.1.3	Distance and Time Separating Discharge Points and Potential Receptors	8-9
8.1.4	Attenuation Processes	8-10
8.1.5	Factors that Contribute to or Diminish Risk	8-11
8.1.6	Data and Knowledge Gaps	8-12
8.2	Risk Issues Relevant to Human Health	8-12
8.3	Risk Issues Relevant to Ecological Health	8-13
8.4	Conclusion	8-22
	References	8-24
<b>APPENDIX 1</b>		<b>A1-1</b>
<b>APPENDIX 2</b>		<b>A2-1</b>
<b>APPENDIX 3</b>		<b>A3-1</b>
<b>APPENDIX 4</b>		<b>A4-1</b>
<b>APPENDIX 5</b>		<b>A5-1</b>
<b>APPENDIX 6</b>		<b>A6-1</b>
<b>APPENDIX 7</b>		<b>A7-1</b>
<b>APPENDIX 8</b>		<b>A8-1</b>

## LIST OF TABLES

### Table

ES-10	Data and Knowledge Gaps	ES-23
ES-11	Estimate of Risk to Human Health Associated with Each Wastewater Disposal Option	ES-24
ES-12	Estimate of Risk to Ecological Health Associated with Each Wastewater Disposal Option	ES-25
2-1	Wastewater Treatment Plants Discussed in This Report	2-3
2-2	Typical Levels of Constituents in Wastewater and Percent Removal Using Treatment (Primary and Secondary)	2-13
2-3	National Standards for Secondary Treatment	2-14
3-1	Representative Human Health and Ecological Stressors Selected for this Study	3-8
3-2	Microbial Pathogens Potentially Present in Untreated Domestic Wastewater	3-9
4-1	Dade County – Representative (Weighted Average) Hydraulic Conductivity, Porosity and Thickness of Hydrologic Units	4-9
4-2	Pinellas County – Representative (Weighted Average) Hydraulic Conductivity, Porosity and Thickness of Hydrologic Units	4-10
4-3	Brevard County – Representative (Weighted Average) Hydraulic Conductivity, Porosity and Thickness of Hydrologic Units	4-11
4-4	Concentrations of Representative Organic and Inorganic Stressors	4-25
4-5	Representative Pathogenic Stressors	4-26
4-6	Pressure Head from Buoyancy and Injection (Scenario 1)	4-37
4-7	Pressure Head from Buoyancy and Injection (Scenario 2)	4-37
4-8	Times of Travel to USDWs and Hypothetical Receptor Wells	4-38
4-9	Estimated Horizontal Travel Distances	4-39
4-10	Range of Travel Times to Hypothetical Receptor Wells	4-42
4-11	Concentrations of Representative Stressors at USDWs and Hypothetical Wells	4-44
4-12	Assumptions Used for Florida DEP’s Human Health Risk Assessment for Reuse	4-48
4-13	Coliform Standards	4-49
4-14	Pathogen Concentrations in Water Corresponding to $1 \times 10^{-4}$ Risk	4-50
4-15	Microbial Transport in Aquifers	4-51
4-16	Survival of Microorganisms in Water	4-53
4-17	Inactivation Rates for Microorganisms in Aquatic Media	4-54
5-1	Reclaimed Water Reuse Activities in Florida	5-3
5-2	Reuse Flows for Reuse Types by DEP District and Water Management Districts	5-4
5-3	Effluent Travel Times in the Surficial Aquifer	5-17
5-4	Initial Concentration of Representative Stressors in Reclaimed Water	5-18
5-5	Contaminant Transport and Fate in the Surficial Aquifer	5-20
5-6	Comparison of <i>Cryptosporidium</i> Concentrations in the Environment	5-23
6-1	Characteristics of Southeast Florida Ocean Outfalls	6-1

6-2	Federal and Florida Class III Water Quality Criteria and Guidance Values for the Indicator Bacteria Groups	6-10
6-3	Typical Concentrations of Fecal Indicator Bacteria in Raw Untreated Sewage	6-14
6-4	Average Current Speeds (cm/sec)	6-23
6-5	Flux-Averaged Initial Dilution of Effluent Plume	6-24
6-6	Recommended Mixing Zone Ranges for Unchlorinated Effluent, Using Different Methods of Calculating Bacterial Concentrations	6-29
6-7	Maximum Allowable Concentrations of Indicator Bacteria in Effluent within Different Mixing Zones	6-30
6-8	Comparison of Circular Mixing Radii for Effluent and Outfall Distance from Shore	6-31
6-9	Nutrient Concentrations in Secondary Treated Effluent, Ambient Water, and in the 400 m and 800 m Mixing Zones for Three Ocean Outfalls	6-33
6-10	Priority Pollutant Metals Detected in Treated Wastewater Effluent Exceeding Class III Marine Water Quality Standards	6-38
6-11	MBAS Concentrations in Effluent and Calculated Dilution Concentration at 400 Meters from the Boil	6-40
7-1	Criteria for Surface-Water Quality Classifications	7-9
8-1	Relevant Risk Assessment Issues for the Four Wastewater Management Options	8-2
8-2	Relevant Issues for Human Health	8-13
8-3	Relevant Issues for Ecological Health	8-19



## LIST OF FIGURES

### Figure

ES-1	Municipal Wastewater Treatment Plants in South Florida	ES-2
ES-2	Use and Disposal of Effluent and Reused Water in Florida	ES-3
ES-3	Wastewater Management for Selected Counties in South Florida	ES-4
ES-4	Levels of Treatment and Disinfection for the Four Disposal Options	ES-5
ES-5	Conceptual Model of Potential Risks for the Deep-Well Injection Option	ES-7
ES-6	Hydrologic Profile of South Florida Aquifer System	ES-8
ES-7	Representative Hydrogeologic Cross Sections	ES-9
ES-8	Migration of Wastewater by Bulk Flow from a Deep-Well Injection Zone	ES-12
ES-9	Effluent Plume Characteristics for Ocean Outfalls	ES-17
1-1	The South Florida Study Area	1-3
2-1	Municipal Wastewater Treatment Plants in South Florida	2-2
2-2	Wastewater Management Options and Design Capacities for Counties in South Florida	2-4
2-3	Hydrologic Profile of South Florida Aquifer System	2-9
4-1	Locations of Class I Injection Wells in South Florida	4-2
4-2	Representative Hydrogeologic Cross Sections	4-5
4-3	Geologic Profile of South Florida	4-7
4-4	Fluid Movement Associated with Class I Deep Well Injection Facilities in South Florida	4-13
4-5	Conceptual Model of Potential Risks for the Deep Well Injection Option	4-23
4-6	Migration Following Deep Well Injection; Fluid Through Porous Media (Scenario 1)	4-31
4-7	Migration Following Deep Well Injection; Bulk Flow Through Preferential Flow Paths (Scenario 2)	4-33
4-8	Final Concentrations of Representative Stressors Versus Time	4-61
5-1	Conceptual Model of Potential Risks for the Aquifer Recharge Option	5-15
6-1	Locations of Ocean Outfalls in Southern Florida	6-2
6-2	Effluent Plume Characteristics for Ocean Outfalls	6-4
6-3	Circulation Characteristics of the Western Boundary Region of the Florida Current	6-7
6-4	Conceptual Model of Potential Risks for the Ocean Outfall Option	6-20
6-5	Initial Dilution as a Function of Current Speed and Discharge Rate (Miami-Dade Central Outfall)	6-26
6-6	Total Physical Dilution as a Function of Distance from the Boil (Four Ocean Outfalls)	6-27
7-1	Conceptual Model of Potential Risks for the Surface Water Option	7-18

[ This page intentionally left blank ]